The Radio Frequency Spectrum as a Finite Natural Resource
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Austin Egbert:

Greetings and welcome to Mind Matters News.

I suspect there's a good chance that right now you're listening to this podcast with an assist from wireless technology. Maybe you are using some Bluetooth headphones or streaming the episode from a Wi-Fi or cellular connection. Even if you're at a desktop computer with a wired ethernet connection and wired keyboard and mouse, I wouldn't be surprised if that very mouse has an optical sensor that uses the same electromagnetic spectrum shared by all other wireless applications today, from missile defense to weather forecasting. With so many systems and users, it's no surprise that managing all these devices is a big job to tackle. Fortunately, we're joined today by all-around spectrum expert Andrew Clegg, to talk about just how it is that we're able to keep the spectrum in check and avoid wireless chaos. Enjoy!

Robert J. Marks:

Greetings and welcome to Mind Matters News. I'm your broadband host, Robert J. Marks. Today we're going to talk about the radio spectrum as a natural resource. When we think of natural resources, we think of things like forests, oil, and gold. Some natural resources are renewable. Forests, for example, are a crop and can be replanted for use by future generations. The supply of gold and oil in the other hand is not renewable. The supply is finite. Once all the oil is used up, it's gone. Once all the gold is mined, it's gone, at least all of the gold here on earth. No new supply is going to be made available. Land is a natural resource. Although available land is finite, it can be used and then repurposed.

A similar non-renewable, but finite natural resource we rarely think about is the radio frequency spectrum used for a multitude of purposes. This includes things like broadcasting of TV and radio and weather forecasting, and the use of your cell phones. If you're old enough, you know what FM radio is. You can tune to different stations on your FM dial, but the number of available stations on the FM radio band is not limitless. Once the band is filled up, there is no more room for radio stations and unless a station goes off the air and makes room for another one. This is kind of what's happening to the entire electromagnetic spectrum. It's being filled up and there's little room for new users. This is not good news. The spectrum today is in high demand. That's you and me, of course, using spectrum for our cell phones. Broadcast media for TV and radio stations need the spectrum. The military uses the electromagnetic spectrum for communications, and yes, radar. Radar uses the electromagnetic spectrum, so the EM spectrum or radio spectrum is also needed for so-called radiometers. Radiometers are used to predict the weather. And spectrum is needed for telescopes, radio telescopes, to observe the cosmos.

So how are we going to manage this traffic jam? Our guests today are top experts in all things spectrum Dr. Andrew Clegg received his PhD from Cornell University and is our guest. He is currently with Google, where he works on spectrum engineering issues in support of the company's wireless projects. Before Google, Dr. Clegg served at the National Science Foundation. While at the NSF, he created and ran the Enhanced Access to Radio Spectrum Program. And of course, the success of any program is proportional to its acronym, and this is a really good acronym, Enhancing Access to Radio Spectrum has an acronym of EARS, E-A-R-S, so that's kind of cool. Also, joining us is Dr. Austin Egbert. Dr. Egbert received his PhD from Baylor University where he is currently a research scientist for the Wireless and Microwave Circuits and Systems Program. Regular listeners to Mind Matters News know that Dr. Egbert is the director and the editor of this podcast. So both of you welcome. And let's go ahead and just start with the fundamentals, just the basics. Dr. Clegg, Andy, if I could, describe the spectrum. What is the spectrum?

Andrew Clegg:

Well, first thanks for having me on the podcast, Bob. I appreciate being here with you and Austin. You did a pretty good job in your intro of explaining what the spectrum is. It really is the collection of frequencies that are used to provide all of these different services that go out over wireless devices and systems. So like you mentioned, our cell phones require certain frequencies. Radars require certain frequencies. Dispatch radios, fire and police radios, they all require their own frequencies. They can't generally talk on the same frequency, at the same time, at the same place, without causing interference to each other.

And traditionally, this hasn't been a huge issue because you think about it back when Marconi around the early 1900s was just first coming online with radio broadcasting and ship to shore communications and things, there weren't that many users of the spectrum. But we've come a long way in the last 125 years or so, and we now rely on a daily basis for the radio spectrum for just so many things. You don't even think about it because it's invisible, but we rely on it for so many things. And the number of things we rely on it is growing and the amount of spectrum that's used by our devices, individual devices, is growing itself.

So you talk about cell phones, that's one of the biggest growing demands. We all want faster download speeds. We want to be able to stream videos on demand. And videos used to be low resolutions, 640 by 480 pixels, and then they became HD, 1080 by 1024 or 1240 pixels. And then they became 4K, so even four times as amount of information has to be streamed. So as we just go for more apps and more streaming and more things, our cell phones are consuming more spectrum. But national defense is taking more spectrum as we want better radar systems to monitor incoming missiles or incoming aircraft or all sorts of things. Our skies are getting more crowded with airplanes, and so we have more air traffic communications, we have more air traffic control radars, and on and on and on.

So all of these things take spectrum and we're getting to the point where there really are no good new frequencies that aren't already being used by somebody. And let me just say, when I say good frequencies, the radio spectrum spans a very large range of frequencies. But just like in real estate, there are some areas of the spectrum that are better than others, more desirable from a number of technical perspectives, and those are the ones that are under the greatest demand. And so we've reached a point where in order to fit more people and more uses into the spectrum, we have to find ways to use it more effectively. We have to share those resources. It's a number of things we have to do, and that's a lot of the technical development in the spectrum field right now is how do we make with the spectrum we have and use it more efficiently?

Robert J. Marks:

So in a way, all electromagnetic frequencies are the same, from AM radio frequencies all the way up to light waves. It's just the number of vibrations per second that it has.

Andrew Clegg:

Yeah, the phenomenon, the phenomenon itself, is the same. It's electromagnetic signals. And so it's the same spectrum, it's the same phenomenon, used for AM radio as FM radio, as TV, as cell phones, as radars. And like you say, it's just a difference in the frequency, the vibrations per second that the radio waves use. We call that measure hertz, H-E-R-T-Z. That's one vibration per second. But typical radio waves that we use for commercial systems often deal in the gigahertz range, so a billion oscillations per second. That's sort of the sweet spot of the radio spectrum, but it's actually even more interesting than that in that it's not just the various radio signals are the same phenomenon, but it's also the same phenomenon that allows us to see things with our eyes. Visible light is just also a manifestation of spectrum.

Of course there, it's something like 500 trillion oscillations per second. It's a much, much, much higher frequency than radio waves. But the phenomena is the same, electromagnetic waves. Same thing with X-rays we use at the dentist's office. That's an electromagnetic wave that's even higher in frequency. If you go back down a little bit lower, there's infrared waves that we use, we feel as heat lamps, or depending on the frequency it's also kind of the invisible light coming from the LED that controls the remote for your TV. That's infrared radiation. And ultraviolet, things that cause suntans and sunburns. Ultraviolet light is even higher frequency than visible light. All of these things are the same phenomena, electromagnetic waves, and they just differ in frequency from one another. But today we're talking about radio waves, which are sort of the lowest frequency electromagnetic waves. And we're going to be concentrating on the radio spectrum because that's the one that we all use on a daily basis the most and is the topic of how do we fit more things into the limited amount of radio spectrum we have?

Robert J. Marks:

One of the things that kind of still blows my mind is the range of frequencies. Like you talked about megahertz. That's 10 to the sixth vibrations per second. To give an idea, if you took 10 to the sixth seconds, that's a little more than a week. If you go to a billion seconds, that is 33 years. And many times we hear something going in the kilohertz, the megahertz, and the gigahertz, and we say, "Ah, that's not a lot of difference." But the difference is astonishing. Again, 10th to the sixth is about a week, 10 to the ninth is 33 years, a billion, I have celebrated, Andy, my 2 billionth birth second.

Andrew Clegg:

Very nice. Very nice. Did you have 2 billion candles on your cake?

Robert J. Marks:

No, no, I didn't. But the party was very short. And then a trillion is 33,000 years.

Andrew Clegg:

Yeah.

Robert J. Marks:

So just the phenomena of these things vibrating this fast, a trillion times a second, just is phenomenal.

Andrew Clegg:

Yeah. Maybe we should go through the units that are used to measure frequency because that might be interesting.

Robert J. Marks:

Yeah, go ahead. That'd be-

Andrew Clegg:

Okay. So hertz, like I mentioned earlier, that's the fundamental unit. It's named, by the way, for a German physicist who first discovered the transmission of radio waves in a lab. But anyway, a hertz is one vibration per second. So the wave goes up and down once per second. Then the next unit that's used is the kilohertz, and that's 1000 vibrations a second. And there are radio waves in the kilohertz range or hundreds of kilohertz range. AM radio is down that way.

Robert J. Marks:

So on the AM radio dial that's in the kilohertz?

Andrew Clegg:

Yeah. So the AM radio dial goes from 540 kilohertz, so 540,000 vibrations per second, up to 1700 kilohertz, which is 1.7 million vibrations per second. And so you can sort of switch to the next unit at that point. And that's megahertz, which means 1 million vibrations per second. And shortwave radio and things like that and some of the aircraft communications and stuff are measured in the megahertz or hundreds of megahertz. And then once you get to 1000 megahertz, that's equal to one gigahertz. That's a billion times a second. And that's where you typically are around the beginning of the ranges used for cell phones and stuff. I mean, there are some cell phone frequencies below a gigahertz, but a gigahertz and higher tends to become the favorable part for cell phone transmissions.

And then you go even higher, you get to a thousand gigahertz, and that's called a terahertz or 1 trillion vibrations per second. And not much activity in the spectrum at those very, very high frequencies of a terahertz. There's a lot of scientific use up there and experimental use, for example, radio astronomy and remote sensing. You were talking about weather forecasting and things. Some of that type of sensing is done in the many hundreds of gigahertz up to terahertz and above.

And it's interesting to mention that, because one potential solution to spectrum crowding, since most of the crowding tends to be at the tens of gigahertz and below, is to move up to these higher frequencies, in the hundreds of gigahertz to terahertz and beyond. But that would be good because lots of available frequencies up there, but the technology isn't quite there yet. The efficiency of devices that can transmit at those frequencies is very, very low. So you would wear down your cell phone battery in a matter of a few minutes if you had to rely on frequencies that high. The transmit efficiency is only about 5%, so 95% of your battery power would go into just wasted heat and other syncs.

Robert J. Marks:

Oh, that's right. And energy is proportional to frequency, right?

Andrew Clegg:

Yes. Energy is proportional to frequency, but also just the fundamental devices, the electronic devices, become less efficient at the higher frequencies, at least the stuff that we use today. So it's one of the reasons why we haven't gone to higher frequencies. There's other problems too. That the atmosphere starts to absorb higher frequencies. Depending on where you are the atmosphere can almost look like a brick wall to some of these frequencies. So you have problems with transmission distance. Antennas become more directional, so your signal tends to be all focused in one particular direction and not in all directions, which under certain circumstances is a good thing. But not all if you're walking around with a mobile phone and things like that. So anyway, that's why moving to these higher frequencies, very, very high frequencies, the terahertz range, we're not quite there yet with the technology, but that's one potential long-range solution to the spectrum crowding we were talking about.

Robert J. Marks:

Well, I think that all frequencies have their own special properties. For example, I can go through my house and go to room to room and my cell phone still works. So those radio waves of the microwave frequency go through walls. But if you get really high in the frequency spectrum, up to visible light, light doesn't go through walls.

Andrew Clegg:

That's right.

Robert J. Marks:

So different things happen at different frequencies. One of the battles, as I understand it, is that there is a sweet spot for cell phone transmission and such and that there's a lot of controversy going on now as to who gets to use this sweet spot in the frequency transmission. I think, is it the S band that is really important?

Andrew Clegg:

So it is. It's sort of the upper S band. Now, of course, I'm a believer that this claim about a sweet spot in spectrum really is more of a trick of the cell phone companies. They've exhausted the lower frequencies and so they've claimed that if you move a little higher, it's the sweet spot. And so they've convinced the regulators they need more spectrum there. I think it's a little bit of a specious argument, but there is some truth to what they say.

The idea is that at the lower frequencies, there's less bandwidth, or fewer frequencies themselves available at the lower frequencies. And as you go to higher frequencies, there's more bandwidth available, more range of frequencies available. But as you go to higher frequencies, the propagation characteristics aren't quite as good. As you noted, you have problems going through walls and the atmosphere could become a consideration, rain and other factors can absorb.

And so the argument is there's sort of this sweet spot where the propagation characteristics are still generally favorable and the amount of spectrum that's available is good too. And so they've sort of come down to the three gigahertz, three to four gigahertz range, roughly speaking, as being the sweet spot in the radio spectrum. And so there's been a tremendous amount of activity in this range in the last few years in the United States and in other countries. So that's what they call at the moment, the sweet spot, and that's the upper S band. S band typically is defined as two to four gigahertz. So three to four gigahertz is kind of a sweet spot.

The challenge we have here in the United States is that the three gigahertz, or about two-thirds of the three gigahertz range, is heavily used by our Department of Defense for military radars, typically shipborne, airborne, and some ground-based radars. And so here in the United States, as we've been trying to get more spectrum for cell phones in the three gigahertz range, we've had to work very closely with the US government and particularly the military to try to share some of these frequencies with their radar systems in a manner where the cell phones don't interfere with the DoD, but at the same time, the DoD's operations don't place too many constraints on the cell phone operations.

Robert J. Marks:

Okay. So the future, that's the spectrum sharing that we're up against. Let me ask you a question. We hear about microwaves all the time. There's microwave ovens. Cell phones use microwaves. Is that right? What's a microwave? What frequency is that?

Andrew Clegg:

Yeah, not well-defined, but a rule of thumb has been that anything over about a gigahertz of frequency is called a microwave. Microwave just means small. And as you go to higher and higher frequencies, the wavelength, the distance between the crest of the waves, because they're vibrating faster and faster becomes less and less, and so they call these smaller waves microwaves. And so sort of the rough approximation rule of thumb has been that above a gigahertz is a microwave. So yes, cell phones do use microwaves.

Now, there are cell phones that operate below a gigahertz. In fact, there's cell phones, T-Mobile is heavily invested in spectrum that goes down to 600 megahertz or so. There are 600, 700, 800 megahertz cell phones in the United States, 900 megahertz in other countries. But most of the cell phone, most of the bandwidth available to cell phones today, is above a gigahertz. And so it's technically, or at least by rule of thumb, considered microwave.

But it doesn't mean that it's the same effect as your microwave oven. So your microwave oven cooks food. And it does it very well. And it does use microwaves. It uses about frequency of about 2.4 gigahertz. And there are cell phone frequencies roughly in that range, not on the exact same frequencies, but your Wi-Fi, for example, operates at the same frequency as microwave ovens. But the radio waves don't cook you. And the difference between a microwave oven and a radio signal is in the power and how concentrated spatially that power is. So your microwave oven is designed, it has a cavity inside. You open the door and there's this kind of box-shaped thing inside where you put your food. And when you want to heat your food, you close the door again. And have you ever noticed, when you look at the door of your microwave oven, it always has a metallic screen over it? And that metallic screen basically keeps the radio waves inside that cavity, inside your microwave oven.

That screen, the little holes in the screen, are much smaller than the wavelength of the radio signal used to heat your food in the microwave oven. When you turn your microwave oven on, a very high-power radio transmitter, typically in the hundreds to maybe a 1000 watts or even more, transmits a signal into that cavity, and because that cavity is closed on all sides and it reflects radio waves, it sets up a very dense radio wave environment where the radio waves are just bouncing inside that cavity. They're not escaping. They're not expanding out into space. They're all concentrated right in that little cavity and they work very well to cause the water molecules in your food inside the oven to start vibrating. And so a microwave oven has been set up very carefully to be very efficient at causing the water molecules inside your food to vibrate when that very high-power radio signal goes off and when it's just concentrated inside that cavity inside your microwave oven.

So that's how a microwave oven heats. And even though your cell phone uses frequencies or may use frequencies around the same frequency of your microwave oven, number one, they use much lower power. Typical cell phone is using about two-tenths of one watt instead of 1000 watts. So it's using 5,000 times less power. And that power is also not purposely concentrated inside a specific cavity to make it bounce around and as intense as possible. When you turn your cell phone on, the signal goes off in all directions and dissipates and things. So the amount of power that you're exposing yourself to from use of your cell phone is thousands and thousands of times less than what a microwave oven is exposing the food to. And so that's why even though you're using the same frequencies, you're not being affected, you're not being heated like food in a microwave oven.

Robert J. Marks:

And that's the reason we read what sounds like an urban myth, that cell phones cause brain cancer. All they do is heat up your ear. Is that right?

Andrew Clegg:

That is correct. So there is, to my knowledge, I'm not a medical doctor, but there is no credible body of evidence that indicates that cell phones cause any kind of cancer. And in fact, if you think about it this way, 20 or 30 years ago, hardly anybody had a cell phone. And today everybody has a cell phone. And in fact, as far as wireless devices go, everybody typically has, well more than one wireless device including a cell phone. I think there's more cell phones in the country than there are people. So if there was a relationship between the use of cell phones and brain cancer, for example, you would've seen in the last 10 or 20 or 30 years just an explosion in the occurrence of brain cancer in the population. And there's no evidence that that's happening. And so there appears to be no body of evidence that indicates that the use of cell phones, 5G, 4G, whatever, causes any kind of cancer.

And to that point, 5G really isn't anything different than 4G. They all use roughly the same frequency spectrum. Some of the 5G systems use higher frequencies. But it's the same technology. It's all electromagnetic waves. There's no reason to believe that any of these systems cause any kind of adverse health effects. Except, the FCC does regulate or does publish guidelines on how strong of radio fields you should be exposed to. But it doesn't do it on the basis of cancer. The FCC has determined there's no basis to believe that any of this causes cancer. They haven't indicated that there's any basis to believe this causes cancer. Instead, they do this on the basis of heating. Doctors believe there could be health effects associated to heating of the inside of your body. Some of the studies they've pointed to are the impact on sperm counts in males where their testicles have been exposed to high heat, hot baths, things like that.

And so there's an assumption that it's possible that heating your tissue inside could have adverse health effects. But the amount of heating that your cell phone creates inside your body is very low, and it actually is regulated. So before any model of cell phone can be offered for sale in the United States, it has to undergo what we call certification. And in the certification process, they use a fake head that has insides that are designed to act like the insides of real heads, and they put a cell phone up to the ear of the fake head, and they transmit the cell phone just like you would if you were on a call going on and on and on for hours. And they have a temperature probe inside the fake head that moves around and maps out the heating inside the head caused by that cell phone. And any heating that they detect has to be below a level that's regulated by the FCC. The amount of radio energy absorbed by the head has to be at or below a maximum level that the FCC dictates.

So any cell phone you use has been tested already to make sure that it's not causing heating inside your head. And again, it is not proven that even if it is causing heating, that it's necessarily causing any detrimental effect. But to be on the safe side, they've made sure that cell phones that are marketed in the United States meet these requirements.

Robert J. Marks:

Would using earbuds diminish the exposure of your ears to radiation?

Andrew Clegg:

Maybe or maybe not. They actually test the earbuds as well, because sometimes the radio energy can actually, so if you're using wired headphones, sometimes the radio energy can actually travel along the wire and into the earbud inside your ear. And then the earbuds themselves, they're not using cellular signals. Your phone is the one using the cellular signals. But your earbuds are communicating with the phone typically by using Bluetooth, which is another type of radio signal, and Bluetooth uses frequencies close to microwave oven frequencies.

And so now you're inserting a radio transmitting device inside your ear itself. So again, these have to meet the exposure guidelines. They're not shown to cause any adverse health effects at all. They're also regulated as to how much heating they cause. But the key in the amount of radio energy you absorb is typically distance. So if you insert something inside your ear, you're even closer to the inside of your body than holding something up against your ear. So you could argue that overall the exposure caused by sticking something in your ear is more than what's caused by holding your cell phone up to your ear.

Robert J. Marks:

Okay.

Andrew Clegg:

But again, all of these are regulated and ensure that the amount of radio energy absorbed doesn't exceed a certain amount that the FCC has deemed to be safe.

Robert J. Marks:

And of course, the best procedure is to use speakerphone. Just get the cell phone away from you, if you are paranoid.

Andrew Clegg:

Yep. Yeah, if you're paranoid, use a speakerphone. In some ways, speakerphones, if you're driving, they're safer anyway than trying to hold the phone up against your ear.

Robert J. Marks:

Sure.

Andrew Clegg:

In a lot of states, that's already, in fact, I would maintain that the danger of you crashing due to holding a phone against your ear while driving is much, much, much... That's a proven danger compared to unproven danger of any adverse effects coming from the cell phone signal itself.

PART 1 OF 4 ENDS [00:29:04]

Robert J. Marks:

Okay. Let me ask you, speaking of paranoia, if you believe people such as Snowden, he says that the government can track your cell phone and monitor your cell phone no matter where you are, whether or not your cell phone is on or off. I don't know the truth of that. Maybe you do, but let me ask you this question. If you were to place your cell phone inside a microwave oven, and of course not turn the oven on, just place it inside the microwave oven, would this block any ability of anybody to monitor what was happening on your cell phone assuming that people could eavesdrop on it?

Andrew Clegg:

Okay, so yeah, it's a big assumption. Yeah, I wouldn't want to get into whether the government can eavesdrop on your phone or not. That's a complicated issue. Certainly tracking cell phones is possible. We do it all the time so that we can get map directions and all sorts of things so you know where to get your Uber Eats delivered to and things like that. So cell phones can certainly, most of them have GPS receivers built into them and things like that. And who has access to those data?

That's a government secret that I don't know anything about. But having worked for the government for a number of years, I think most people put more credence into the government being able to do things. Then the government can really find a way to do so. I put it that way. So the question is if you put your cell phone inside the microwave oven, so the answer is generally yes, that would block the cell phone signals from getting in or out at most frequencies because the microwave oven is designed to keep frequencies inside, keep radio waves of a certain frequency inside. But your phone wouldn't be of much use because you couldn't access it, you couldn't listen to it, you couldn't receive anything or transmit. So yeah, it would be-

Robert J. Marks:

The last thing you want to do is stick your head inside a microwave oven.

Andrew Clegg:

Exactly. But as soon as you open the door to stick your head in there, of course you're now letting radio frequencies in and out. Now, some of the 5G frequencies are very high frequencies that could potentially leak out of the microwave oven. Microwave oven is designed to basically shield frequencies in the 2.4 gigahertz range because that's the range they work at. So at some of the higher frequencies, some of the 5G systems, not the... they thought that the 5G systems operating in millimeter wave frequencies, which are 20-30 gigahertz range were going to be a thing. But they haven't taken off pretty much for the reasons we earlier.

Propagation characteristics aren't very good at those frequencies, and the battery efficiency is very low as you go up in frequency. And so the millimeter wave 5G really hasn't been much of a success. But the point is that some of those frequencies might be able to leak out of a microwave oven because a microwave oven is designed to keep lower frequencies in. But again, that's a far-fetched thing. You'd need a 5G base station very close to your device because they don't propagate very far. But those are some of the considerations.

Robert J. Marks:

So I thought of an experiment I can do, I haven't done it yet, but if I have a Bluetooth headset and I put my cell phone inside the microwave with a podcast going or something and close the door, that should block the podcast right?

Andrew Clegg:

It should, yes. Now... So yes. And the Bluetooth, if you're using Bluetooth headphones in particular, yes, because Bluetooth also operates in the 2.4 gigahertz range. It reminds me of one time I was visiting my dad and he has a cordless phone, and the cordless phone was one of these cordless phones that operates in the two gigahertz range, the 2.4 gigahertz, 2.4 gigahertz if you haven't figured out is a popular place for various unlicensed devices and industrial devices like microwave ovens and Bluetooth and wifi. But he was heating some water to make some tea and he was on the phone and he opened the microwave oven to get his tea out and his call cut off instantaneously as soon as he opened the door.

And it was because the base station for his cordless phone ended up being on one side of the microwave oven door and he was standing on the other side of the microwave oven door, and it just instantly cut off the connection between the two. So yes, you would not get Bluetooth out of your microwave oven.

Now of course, I don't recommend this experiment unless you're extremely careful because you could accidentally turn the oven on and zap your phone and all sorts of things.

Robert J. Marks:

That's what I would be afraid of. My muscle memory would kick in and I'd turn-

Andrew Clegg:

Yes, exactly. Hit the one minute switch or something.

Robert J. Marks:

Exactly, exactly.

Austin Egbert:

Yeah. Unlike the videos that were popular online around when wireless charging became a thing, putting your phone in the microwave will not charge it, at least not in a useful manner.

Andrew Clegg:

Not in a desirable manner.

Robert J. Marks:

I saw a great fake video where they put a microwave... not a microwave, but a cell phone down next to some kernels of popcorn, and then they stopped the video, they took out the kernel and they put a popped kernel in there so that when you played it back, it looked like the microwave was popping the popcorn. That was early deepfake.

Andrew Clegg:

Yeah, phones can't pop popcorn.

Robert J. Marks:

Okay, last question. I'm going to bring Austin in here. Austin, one of the things about the low frequencies in the kilohertz is AM radio. There is a movement now of getting rid of AM radio. In fact, Ted Cruz, my senator here from Texas, is sponsoring a bill to prohibit car manufacturers from discontinuing AM radio, which I think is a terrible idea. I think that that should be left to the free market. But anyway, that's what he's doing. How come these car makers are discontinuing AM radio?

Austin Egbert:

So one of the claims, at least one of the reasons behind it, is with electric vehicles being electrically powered, they end up generating a decent amount of interference at a number of frequencies. And some of the frequencies at which they're generating that interference end up overlapping with some of the AM radio band where it can impact the signal quality that's received by the AM radio. So you end up not being able to hear the stations as clearly as you otherwise could or maybe not be able to really make them out at all.

There are ways to get around that through additional filtering and things like that in the radio systems themselves, shielding them from the rest of the car so that it has a cleaner feed from the car's antenna.

It's mostly just a matter of cost. And I think a lot of the auto manufacturers were kind of weighing the cost benefit analysis and went, "How many people still listen to AM radio and is it worth putting X number of dollars of extra components and design into our vehicles to make this still work out?" And at least initially, a lot of them were looking at cutting them. I think recently many of them have backpedaled and said, "Yeah, we'll go ahead and keep using AM radios in the vehicles."

Robert J. Marks:

Yeah, we'll see what happens. See, I'm old enough to remember. I think this was in the... oh gosh, I'm going to surrender my age here. In the late 50s, early 60s when they had broadcast television and they used to have prop planes, propeller planes, and we would be watching Gun Smoke on television through the air. It wasn't streaming or anything. It was regular broadcast television and a propeller airplane would go above and it would totally destroy the video and the audio signal that we were watching. And it was because the prop plane had this engine which was generating electromagnetic waves apparently in the same spectrum as the broadcast television was. And so this seems to me to be the similar case that we're talking about the banning of AM radio.

Austin Egbert:

And I know Andy had actually listened into some of the congressional hearings on the topic. So Andy, I don't know if you have some more you'd like to add to the subject.

Andrew Clegg:

No, it's a good summary you gave, Austin. Yeah, it really is. It's principally the charging circuits in the cars that cause a lot of noise on the AM band. And like you said, the car manufacturers were like, "Well, who listens to AM radio? Is it worth all the extra money?" And so they just decided to take AM radios out. But the politicians got involved and said, "Hey, some farmers rely on AM radio for weather warnings and other people like to listen to talk radio," and things like that. So maybe Congress should get involved. I'm not a big fan of Congress getting involved in detailed spectrum issues, but there is something to say for keeping AM, and I like to listen to AM radio in the car sometimes. At night, I like to see how far away I can hear stations because at those frequencies the signals bounce off the ionosphere and it's kind of cool to be driving through Virginia and hear stations from Illinois and New York and things like that.

But yeah, it's an interesting, interesting thing and I don't know if people have noticed at home or not because again, I don't know how many people still listen to AM radio at home, but the same thing is happening inside our houses. All the power supplies, typically it's power supplies, the things that power our TVs and computer chargers and phone chargers and everything, they also make a lot of noise that interferes with AM radio and it's getting harder and harder to listen to AM and shortwave radio in homes because of the amount of noise. Another thing that generates a lot of noise is LED light bulbs because they have little power supplies in them, and I think it was this month, I believe August 1st, something, they've now banned the manufacturer's sale and importation of incandescent bulbs. So we all have to use something that is not the traditional light bulb that never generated any noise. And so yeah, we're dealing with it not just in cars, but in homes and everything. So radio noise is becoming a problem.

Robert J. Marks:

Well, I got to admit, I haven't listened to radio in the car for, I don't know, at least a year. I'm a streaming podcast guy. I enjoy those more because I can control the content better.

Andrew Clegg:

Well, Bob, that's what the car manufacturers are... one of the arguments they're making is that hardly anybody listens to the radio, they listen to streaming instead.

Robert J. Marks:

Chances are that right now you have all sorts of electromagnetic signals bouncing off of you and going through you. Think about it. When you turn on your cell phone, the cell phone is using a portion of the radio spectrum. If you have a radio, you can tune to many stations, all of which use a different part of the spectrum. Whether or not you have a radio, these radio waves are present where you sit, so are all of the broadcast television signals. Visible light is part of the electromagnetic spectrum. So unless you're sitting in the dark, wherever you are, you are the presence of hundreds if not thousands of sources of electromagnetic radiation. So here's a problem. There are too many signals and useful spectrum bands that are filling up. The radio spectrum is filling up with users, especially in the so-called sweet spots, in the places where the electromagnetic spectrum has special property. So what should we do? Andy, how do we deal with the spectrum filling up? There has to be some sort of traffic cop somewhere or something. What do we do?

Andrew Clegg:

Yeah, well, so there's basically two ways to deal with the spectrum filling up, two obvious ways. One is to increase the efficiency with which the spectrum is used. So in other words, if you want to transmit a certain amount of data, make your signal as efficient as possible so you can transmit as much data as possible while using the fewest number of frequencies. We call the range of frequencies you use the bandwidth of a signal. So that sort of explains the size of the chunk of the radio spectrum you have to use. So the more data you can transmit to a user on a given chunk of spectrum, then the more efficient your transmission is and you can fit more users into the available amount of spectrum. So that's increasing efficiency. So that's one way of dealing with a spectrum crunch.

Robert J. Marks:

If I could interrupt, using the spectrum efficiently has been something which I think is kind of a well-plowed field. Are we still making advances in this area?

Andrew Clegg:

Yeah, so that's exactly what... I was going to make that point in a minute is that we have done a pretty good job getting close to in some ways theoretical spectrum efficiency in terms of Shannon's law and things like this. But there are still ways to make spectrum use more efficient that isn't purely in terms of the number of bits you can do per frequency. One of the ways that we're becoming more efficient is that we're using much more advanced antennas that are able to beam the signal only in the direction where it's desired and not send radio signals in other directions. So if you have 10 users on a cell site, we're deploying antennas where the signals can be beamed directly at those 10 users and not send a lot of signals off in other directions. So that's another way to improve efficiency and that we're still developing technologies for what we call beamforming, forming the radio beams that you send to different people. That field's still developing and it's getting quite sophisticated, but that's another way of effectively increasing the efficiency.

Robert J. Marks:

Let me ask you this about the cell phone. When you're talking and your cell phone broadcasts, is it omnidirectional? Does it go out with the same power in all directions or is there beamforming that kind of points towards the cell tower because if you point it towards the cell tower, you could do more? I think it's the former, isn't it?

Andrew Clegg:

Well, it depends on the model of phone you have, but typically the more modern phones do in fact have some limited level of beamforming in them, not nearly as much as the base stations because the beamforming requires giant antennas that are many wavelengths in size and multiple antennas that are spaced far apart. In the phone, there are typically multiple antennas, but typically it's going to be two or four, maybe not the number that you can put at a base station. So there's very rudimentary beamforming implemented at the phone. So your signal tends to spread a lot more widely from a phone than it does from a base station, but the amount of power being transmitted by your phone is much less than the amount of power being transmitted by a base station. So if you implement good beamforming at a base station, you are being more effective at limiting how much radiation goes in different directions because the base station is sending so much more power than the cell phone itself. But yes, the cell phone signal tends to be spread out more than the base station signal.

Robert J. Marks:

It seems to me that if you did have... you were able to aim your cell phone signal that you would be using more energy towards the cell tower and wasting a lot less energy, and I think your battery would last a lot longer, wouldn't it?

Andrew Clegg:

So yes, and that's a good thought. And they have implemented some sort of basic features like that. But the reality is when you're talking on a phone, you're typically moving, you might be walking down the street, you might be in a car, you also move your head around and even when you're talking, your jaw is moving, your hand is changing, orientation, all sorts of things are going on that's causing that phone to move or causing the electromagnetic environment immediately surrounding that phone to change.

And so having a good stable beamforming solution gets much more difficult on the handset side. On the base station, the antennas are absolutely stationary. You can also have a lot more computing power at the base station to do all the calculations to do the beamforming. And so in practice, it's a lot easier to implement beamforming on a base station than a handset. So yes, you're right, it would be ideal if you could have just a very narrow beam coming from your phone back to the base station, but in practice the amount of size and power and things that you would need to implement that and you'd have to stay very still to make it stable, it just isn't practical to have very high beamforming efficiency from a handset.

Robert J. Marks:

Okay, that makes a lot of sense. Let me ask you another question. This is spectrum sharing in a way. When you're on the airplane, the flight attendants come on and say, "You got to turn off your cell phones," why? What is that going to interfere with?

Andrew Clegg:

So it's interesting, it's not an FAA regulation that makes you... that is basically telling them to tell you to turn off your handsets on the plane. It really is an FCC rule and there's a variety of reasons for it. The basic reason from one of the FCC rules is that it's possible that a cell phone transmitting up in the air can interfere with many base stations at one time. So one of the ways that a cell phone network is designed is that a base station may use the same frequency as a neighboring base station uses in the same company's network, or they may have a grid of frequencies that are very carefully mapped out between cell sites to reduce the chance of cell sites interfering with themselves. And the assumption there is that the mobile devices are typically going to be where they're expected to be and that is on the ground or in a building or something generally close to the ground.

When the cell phones get up in the air, in the air you can see for a very, very long way, which means your radio signal can also go for a very, very long way. And the concern was that you could cause disruptive interference to cell phone networks from a single cell phone on a plane that's interfering or signal being received by multiple cell sites at the same time. So that's one reason. The other reason is that there are sensitive avionics on a plane like aviation radars that measure the distance between the plane and the ground or air traffic control frequencies or weather radar that's built into the nose of the plane. There's a number of systems on the plane that use radio waves and there's always a potential that if you're using a cell phone transmitter inside the plane that it could interfere with some of the plane's avionics. But the reality is the avionics are generally well-made.

Traditionally, the frequency separation between where cell phones operate and where the plane's radars and things operate was significant and there's no... I don't believe there've been any documented airline incidents caused by actual interference from a cell phone to avionics. So I think the concern is a bit overblown, but still probably not a bad idea not to have your cell phone on the plane.

But of course these days now that you can get wifi on most planes, they're basically inviting you to turn one of the transmitters back on your phone, which is the wifi transmitter. And in fact, some planes, not so much in the US but sometimes in Europe and other countries, they actually can have little cell phone base stations on their planes. And so you can use your cell phone in cell phone mode. So obviously the fact that this wireless infrastructure exists on planes must mean that the chance of interruption to the avionics caused by your cell phone is relatively low, but for safety's sake, it's always a good idea. If they ask you to turn your cell phone into airplane mode and just keep the wifi on or whatever, it's probably a good thing to do.

Austin Egbert:

Yeah, it can also help with your battery life if it's not having to constantly search for a cell signal that it can't find many tens of thousands of feet in the air, so...

Robert J. Marks:

Another concern that I have heard about is that the altimeters for airplanes can be disrupted not necessarily by signals within the plane, but signals external to the plane, in other words, signals in the vicinity of the airport. And can either one of you elaborate on that, tell me whether what I've heard is wrong or right?

Austin Egbert:

Yeah, so basically what was going on there was with some of the rollout to 5G cellular networks is that one of the bands that was allowed for use was next door to a band that has been used for aircraft radio altimeters. Basically these are sensors where the plane's able to send a signal down towards the ground as it's coming in for a landing or a departure, and then it listens for the reflection of that coming back up from the ground and based on time of flight and whatnot, it can get an idea of how far away it is from the ground below it.

In theory, there shouldn't be any issue because it's using one frequency and the 5G systems are using a different frequency, if I remember correctly, a slightly lower frequency. The problem is that most devices, it's very difficult to create something that only transmits in this one particular set of frequencies and nowhere else. You end up with what's called sort of a spreading of your signal where the electronics... you end up with sort of a roll off. Most of your energy is in the band you wanted it in, but you still kind of leak a little energy transmitted on adjacent frequencies. And the concern was that some of this leaking energy would get close enough to some of the aircraft altimeters such that it could cause interference with the systems on those planes. And specifically, they weren't even necessarily worried about even the leakage being too close, but rather that some of the older systems on the planes would have filters that were too wide and so newer systems didn't necessarily have this issue on the planes because it would have a narrower filter.

Robert J. Marks:

Okay, filter. Explain what a filter is.

Austin Egbert:

Yeah, so essentially a filter works where you're able to turn down the amplitude of certain frequencies. So the filter will be designed where it only allows signals of certain frequencies to pass through it.

Robert J. Marks:

Well, in fact, that's what you do with your AM or FM radio station is you tune it so that only the frequency of that station gets through.

Austin Egbert:

Yes, exactly. Yeah, you can tune the filter, the band that the filter is designed to let through into the radio receiver, and that's how you can choose which signal you want to listen to. So these aircraft altimeters would have a filter that was designed where it would only be able to pick up the signal that it was sending down and then the reflection of that coming back up.

Robert J. Marks:

So a filter that was too wide would be, for example, on your FM radio station, your filter would be too wide and you would actually be hearing two or three radio broadcast at the same time instead of one. That would be an example of a filter that had too big of a bandwidth?

Austin Egbert:

Yes. Yeah, yeah. Essentially the older filters were with older technology, they didn't have as sharp of a cutoff. So if you think of, I want to only listen to frequencies from A to B, ideally I would have a sharp cutoff and I wouldn't hear anything outside of that range. But in practice you get some sort of roll off where you hear some frequencies below A and some frequencies above B. The sharper you can make that cutoff, the more of an ideal filtering you get. Some of these older systems, the slopes were shallow enough, they weren't sharp enough of a cutoff, that there were concerns that some of the signals coming from those adjacent 5G systems would be able to leak through and still make it to the receiver of the aircraft systems and potentially cause issues.

Robert J. Marks:

So in your opinion, should we be concerned about the overflow of frequencies that are in the same frequency area as altimeters? Should we be careful about keeping those out of airports?

Austin Egbert:

I think in this case, the solution is pretty well identified. It's just a matter of going in and updating those aircraft systems to have newer, sharper filters. It's kind of understandable why things progress the way that they did. Typically, in aviation, there's a very well-motivated mindset of if it's not broke, don't fix it. And so if the existing filters were working fine, there was not a need to replace anything, and you're potentially introducing additional risk by updating a system that you don't need to when the old system is working fine and has worked fine for decades. But in a situation like this where, okay, now we've brought these new systems in, now there's a motivating reason to go ahead and modernize some of those systems and implement sharper cutoffs that should improve the quality and performance of those systems. But because it was something new, it just didn't have the same reliability track record as something that had been around for forever.

Robert J. Marks:

Gotcha. Interesting. Let me ask you about another case where maybe we got to watch out for electromagnetic pollution, and these are radiometers. What is a radiometer? And I believe that they're used to help forecast the weather right?

Andrew Clegg:

So a radiometer is a device that measures basically natural radio emissions coming off of objects such as the Earth, either the land or the ocean, or even the atmosphere. We don't realize it, you don't often think about this, but anything that has a temperature above absolute zero radiates energy at all frequencies, and I do mean anything, you, me, the walls in your room, the computer you're sitting in front of, your phone, anything, even if it's not transmitting wireless signals, anything, just by virtue of having a temperature emits electromagnetic waves at all frequencies.

Robert J. Marks:

Wow.

Andrew Clegg:

Yes, which is very interesting. The thing is, the amount of radio waves, the strength of the radio waves they generate is very, very low. We typically call this... if something's radiating just because it's got a temperature, we call that thermal emission. And the thermal emission coming off of typical things like your body or your dog or whatever is very, very low. You typically wouldn't be able to pick it up with your AM radio in your house and things like that. But there are certain systems that are designed to listen specifically for this very, very weak electromagnetic radiation coming off of natural objects. And there's two types of systems that are designed to do this. One is a radiometer, which is typically used in monitoring the Earth. So they're often on satellites looking down at the earth and they're measuring, for example, the temperature of the land or they're measuring the... salinity of the oceans, or they're measuring the amount of attenuation caused by the atmosphere. So they can try to measure the water vapor content in the atmosphere, or perhaps even measure the water vapor content as a function of height in the atmosphere. They do all sorts of things by these radiometers.

They're measuring just the thermal emission coming off of the water, the land, the atmosphere, or whatever. And these data are fed into weather forecasting models. So you think about trying to monitor what the sea surface temperature is. So if you're trying to figure out whether you've got the kind of heat in the water that can cause evaporation and create hurricane type conditions and things, as the water evaporates and current convection currents start happening in the atmosphere, some of these measurements they make with radiometers on the satellites, looking at the oceans from above can tell you that. And then also mapping out the water vapor content in the atmosphere can tell you how likely it is that it's going to rain, or thunderstorms develop, or whatever. And so these are passive instruments in the satellites that listen for this very, very weak, but pervasive, thermal emission coming off of objects in the space.

And the other type of system that listens to natural radio waves are radio telescopes. They're typically on the surface of the earth, and they're pointed out at the cosmos. And things in the cosmos, other galaxies, or extended clouds of gas, or all sorts of things, also create natural radio emissions, although they're very, very weak. But with these big giant dishes that they put on the ground and operate as radio telescopes, they can collect enough signal to measure it.

So these are fascinating things being done, very important things being done, with weather radiometers and forecasting weather and hurricanes and things, and very important science being done in radio astronomy. But, as mentioned, these natural signals are exceedingly weak, and so those types of systems that use this radio spectrum to listen for this very weak emission are particularly sensitive to interference because Austin was talking a few minutes ago about the tiny amount of leakage that could come out of a cell phone signal, because it goes beyond its intended frequency, and the amount of signal that comes out that goes beyond its intended desired frequency can be 1,000, or 10,000, or 100,000 times less than the signal that comes out at the intended frequency. And for the most part, that doesn't have a major impact on other systems in the radio spectrum, but that amount of signal leaking into a band that's used for radiometers on a satellite, or leaking into a band used by a radio telescope that's not very far away, could completely disrupt the radiometer or radio astronomy observations that are being made.

So those systems are very sensitive to what we call these out-of-band emissions, and it's a constant battle. The people who operate these satellites and the radio astronomers will tell you that it's a constant battle trying to fight sources of radio interference to their systems. They'll also be the first ones to tell you that a lot of the radio interference they have to deal with comes from themselves. I began life as a radio astronomer, and most of the interference to radio telescopes turns out to be caused by electronics that are used to run the radio telescope, and they have to spend an amazing amount of time tracking down signal leakage and interference coming from the various electronic systems they have at the observatory, but they also have to deal with interference coming from cell phones operating nearby, and even satellites overhead that are transmitting signals down and stuff.

And this is such a challenge, by the way, people may have heard that there is what's called the National Radio Quiet Zone, which basically covers a good chunk of West Virginia, and part of Virginia, and part of Maryland. And it's this big zone. It's not where no radio signals are allowed, but if you want to put certain types of radio transmitters, like fixed radio transmitters that are on a cell tower or whatever, you have to coordinate with one of the major radio astronomy observatories, the Green Bank Observatory that is in West Virginia, and they will run calculations and make sure that the system you're putting up won't cause signals that will disrupt their radio astronomy observations. So this is this 13,000 square mile area. If you wanted to put up a cell tower, you've got to coordinate with Green Bank, and they'll make sure you're not going to interfere with them.

It's a constant battle. And as the spectrum fills up and there's fewer places for people to do their science and their wireless transmissions and stuff, these interference cases pop up more and more.

PART 2 OF 4 ENDS [00:58:04]

Robert J. Marks:

That is fascinating. So we have to make sure that these radiometers and such are not polluted with all of the application of new frequencies that we're talking about, or new uses for the frequency of the greater demand. Really interesting.

Okay, new topic. Austin, I know you have some thoughts about this. What is 5G? I hear it all over the place. 5G this, 5G that, some places they're talking about 6G now. What is 5G? I don't know. I'm an engineer, I should know, but I don't know. What is 5G?

Austin Egbert:

The simplest answer is 5G is just basically an acronym standing for fifth generation. And so it's kind of an umbrella term over all of the different cellular communication technologies that have been considered to be under the fifth generation of wireless communication standards.

So 5G implies the existence of earlier Gs. You had 1G, first generation, nobody really called it a generation at that point. It just was cellular communications. Eventually, we had 2G, which wasn't really a term that was popular, I don't think, at least I don't recall hearing it at the time. 3G eventually came along, and you started hearing things about 3G phones. If I remember right, I think the iPhone, one of the early models of it, was branded as the iPhone 3G, kind of in a reference to that third generation of cellular technologies. 4G is maybe more commonly known as LTE. I think a lot of phones will show if you're on a 4G standards network, it will show an LTE near the signal strength.

Robert J. Marks:

What does LTE stand for?

Austin Egbert:

If I remember right, I think LTE stands for long-term evolution. There's kind of been this idea within the wireless industry, if they want to move away from these sort of big changes to standards over time and have set up a situation where they're able to make changes gradually over time, rather than just release a whole new standard of a bunch of things in one go, and so that's kind of where that sort of LTE term came from.

One of the problems with that, that I think some companies are realizing, something I think similar has maybe happened with Microsoft recently, is that if you just change things a little bit over time, you never have a big moment where you can market something new to people. If it's just always getting a little bit better and a little bit better, there's no big marketing push you can make around that.

Something similar happened with Windows. They released Windows 10, and they said, "This is going to be the last version of Windows ever. We're just going to constantly improve it, and it'll change over time." And then just here, in the last couple years, we've had Windows 11 show up. So despite saying Windows 10 was going to be the last version of Windows ever, now we have Windows 11, which they were then able to market as this nice new thing because it was a lot harder to market, "Oh, here's the biannual update to Windows 10 that's introduced some new things."

So I think something similar happened with going from 4G to 5G, is that everyone went, "Oh, if we just keep changing things, when can we ever say our systems are much better?" And you need to go buy a new phone to take advantage of all of these cool new things.

Robert J. Marks:

So you're saying 5G is largely a marketing ploy?

Austin Egbert:

No. So I think what ended up happening is, it's one thing to say, "Yeah, we're going to just sort of evolve these standards over time." If you don't have a concrete set of, "Here's the new things," it becomes sort of this mess of organization in a lot of situations, where it's like, "Okay, well, what things do you support?" Because, as you go on over time, eventually, you kind of have to drop support for something.

Having those 2G, 3G kind of identifiers has helped with that because cell companies have been able to say, "Okay, we're shutting down our 2G network. We're not going to keep the equipment in the field that supports those technologies. We've moved on to the newer stuff that we would rather maintain." And so, hypothetically, if you were to try and keep everything within LTE long term, it would become a mess of saying, "Well, what things within LTE do you or do you not support?" So having an umbrella term can be useful when you want to talk about compatibility of different situations.

So 5G did end up rolling out, and it has had a significant number of changes within it. One of the main things that's happened is there's been a discussion of millimeter wave 5G. I think, I don't remember the marketing term for that band, but it's essentially they have started trying to use some wider bandwidth signals than had been used in previous cellular technology generations. And so there is actually new stuff in 5G.

However, some people may remember early on, I think this was possibly early 2020, AT&T launched what was called 5Ge, which what they explained as meaning 5G Evolution. And this stirred up quite a bit of controversy amongst consumers and other players in the wireless industry because 5Ge really did have nothing to do with 5G. It was just a rebrand. It was a rebrand of a bunch of things that had happened in LTE, new technologies that had been introduced, as early as even 2017.

So AT&T customers had had the 5G technologies potentially from 2017 onward, but in 2020, AT&T said, "We want to be the first ones to 5G. 5G currently doesn't exist anywhere yet, but we want to beat everyone else to it. So we'll slap a new coat of paint on these LTE features and call it 5Ge. We'll justify it as being these are technologies moving us on the way to eventual 5G." But they were pretty widely criticized as it being a blatant marketing grab without much technical substance behind it. So there's some instances where you have to be careful with, what's 5G, what's 6G?

Early on, in any type of standard, no one really knows what 5G is. But it ends up just being the camp within which everyone just talks about what they want to have happen in the next wireless generation, next cellular generation. We're seeing something similar now with 6G. You asked, "What is six G?" No one really knows at this point. There is not a 6G standard that has been established. They're in development. People are trying to figure out what new features and capabilities are we going to try and package together and put into some upcoming standard.

But if somebody comes along and tells you, "I know exactly what 6G is going to be, it's going to do this, that, and that," at this point, it's basically just pure speculation. And in many cases, maybe just marketing hype because, again, everyone wants to kind of be the first to something, because then you can claim, "Oh, I was the first one to have a 5G network." Well, people want to be the first ones to have a 6G network, because then that's a big marketing buzzword that they can give to consumers and things like that to try and drum up business.

Robert J. Marks:

That's interesting. One of the things in order to accommodate all of the new users of cell phones is to go to different frequencies. And, Andy, I think you were telling me that when this happens, we're going to have to rethink and redo our infrastructure on how we use it, that our current spacing of towers is going to be too far apart. Could you elaborate on that a little bit?

Andrew Clegg:

Yeah, I mean, I think that's yet to be seen still, but as you go to higher frequencies, the signals, in general, don't propagate quite as far. In other words, the signal becomes weaker faster. And so especially in the millimeter wave 5G that Austin was talking about, the signals, they typically can't penetrate into buildings. They typically don't bend around corners very well and things like that, like signals at lower frequencies do. And so in the extreme case of the millimeter wave 5G, if you want to have that in a city, you need a cell every block. You need to basically have line of sight. You need to be able to see that cell with your own eyes in order-

Robert J. Marks:

So how far apart today are cell towers?

Andrew Clegg:

Well, so it depends. If you are in a rural area and they don't need to serve a very high density of customers there, there could be 10 or 15 miles between cell towers, in theory. If you're on a flat area and you've got good visibility around you, they don't need to be spaced very closely.

But at millimeter wave frequencies, again, sort of the opposite situation. You're in a city with buildings and things, you need to have them basically on every block, and that's very expensive. Not only is the hardware expensive, but you have to have fiber, power, and everything run to every one of these base stations in order for them to function.

So we call that densification. So you either have to densify because your signals aren't traveling very far, like we have in the case of the millimeter wave 5G, or you have to densify if your users are using a lot of bandwidth, because a given cell tower can only provide over the air, can only provide a fixed amount of bandwidth to all of the users using that cell tower.

So if you have too many users demanding too much bandwidth from a tower, some of those users aren't going to be able to do what they want. Their videos are going to buffer or whatever, and so you have to put up more cell towers so that you can serve more people in a given area. So that's also an example of densification. In that latter case, it's because of the capacity. You need more capacity for your cell network, so you have to put up more cells. In the former case, it's a propagation, it's a coverage-based densification. You need more cells just to be able to cover an area with a usable signal.

So in my opinion, millimeter wave 5G has not been particularly successful because, first of all, the users realize that their signal cuts out immediately upon going into a building or going out of a building if the cell happens to be in the building, or just going around a corner, they lose it. And the phones are also, as we mentioned earlier, their phones are less power-efficient at those frequencies. So your batteries don't last as long. So I don't see millimeter wave 5G as being a big commercial success that's going to be replicated on grand scale in other generations.

Now, of course, a lot of people, the big dreamers, believe that 6G is going to be about going to even higher frequencies, providing even more bandwidth, and being able to send a hundred gigabits per second to a phone. I don't see that as being the driving force. And I think the experience with millimeter wave 5G shows that going to higher frequencies has enough problems that it's probably not the future.

So I sort of see that the typical cell spacing now of a couple of kilometers or somewhere around there, on average, if you took suburban and urban areas, maybe two or three kilometer average separation between base stations, I would think that that's probably what we're also going to see as 5G evolves, but I guess we'll see. If a killer app comes out that just demands a tremendous amount of bandwidth, augmented reality takes off, and people don't mind walking around wearing those crazy looking headsets, maybe we will need more cell sites. But at the moment, my prediction is I don't see that happening in the near term, and who knows what will happen in the longer term.

Robert J. Marks:

That's fascinating. I believe, if I remember right, I saw a startup company that was concerned about the problem with the propagation of these higher frequencies. And so they were developing a technology that you could put, for example, in a window. Now, in a window, I mean, you would have to cut out a circle in the window and put this device in it, so that the window wasn't in the way, or you could even do it as a wall, and on one side would be a receiver for the signal, and there would be a retransmission on the other side in order to beat some of these problems. So that was a solution. I think that would work, wouldn't it?

Andrew Clegg:

Yeah, not a bad idea, and you mentioned windows. So one of the challenges that is occurring basically at all frequencies now is that, as buildings are made more energy efficient, a lot of the technologies that make a building more energy efficient are also good at blocking radio waves. And in particular, with windows, they will often put a conducting thermal film on the windows in order to keep heat or AC in, in other words, to keep what you want on one side of the window away from what you don't want on the other side of the window in terms of heat or cold or whatever.

And those same methods of manufacturing windows that make them hold up well to thermal electromagnetic waves going in and out is also blocking radio waves from going in and out. And so some of these highly efficient buildings have very high attenuation, and it's not just at the higher frequencies, it's basically at all frequencies. And so it's getting harder to serve the inside of buildings with radio cellular signals these days because of the attenuating effects of these types of thermally efficient windows.

Now, a lot of times we don't notice it because we tend to switch over to Wi-Fi or something that's inside the building, rather than relying on cell signals. But a lot of the current buildings that are out there, the cell signals just don't penetrate in very well.

Robert J. Marks:

The U.S. government is in charge of the spectrum in the United States who uses it, and even the call letters of the stations. During college, I was a disc jockey at a 50,000-watt radio station, WPFR. The PFR stood for Paul Ford Radio. Paul Ford was the man who built and owned the station. I also worked at WKZI. KZI stood for Casey, Illinois where the station was located. In both cases, the call letters started with W. This is required by the U.S. government.

In 1912, the United States met with other countries and do letters out of a hat. The U.S. was given the letters W, K, N, and A. The letters N and A were given to the military stations, but K and W were assigned for commercial use. All commercial stations east of the Mississippi River had to start their station call letters with a W, and stations west of the Mississippi with a K.

Interestingly, the W assigned to the U.S. is the only letter in the alphabet. And think about this, this is deep. This the only letter in the alphabet that has more than one syllable. The other letters have one syllable. So this was bad for radio and TV announcers that had to learn how to say W. And if you want to find out whether a broadcaster is a pro or not, the broadcaster will say W instead of W. So it's WPFR, not WPFR, so that's a good filter if you're listening to somebody who's on a local radio station. Canada, by the way, got the letter C for its commercial stations.

Government control of the spectrum continues today and is way beyond just assigning call letters. The government dictates who can broadcast over what channel and what frequency band, but the spectrum today is pretty crowded. It turns out the government needs to do something. The spectrum is all used up, especially in the very useful and popular bands. We have the perfect people to talk about this today. Andy, who determines what frequency bands are assigned to who, and how do they do it?

Andrew Clegg:

Well, that's an interesting question with a little bit of history behind it. I won't go into too much history, but in the decades past, there were typically enough frequencies to go around for everybody. And so pretty much the first person who applied for a particular frequency, band, or whatever, would be given that frequency. And that worked for quite a while, until maybe starting 40, 50 years ago. It started to become harder to find frequencies, particularly for broadcast stations, dispatch services, and other systems.

And so the FCC went to a process of basically comparing the different applications. People have pejoratively called this a beauty contest. But the FCC would look at the applications, look at what the applicants were planning to use the frequency for. It would make a determination as to which one served the public interest better, based on a variety of factors or whatever, and then give that entity the license for that frequency or that band.

But then some economists started looking into this, and they realized that you really should find a way to give spectrum to those who value it most. And the argument would be that those who value it most are, from an economic standpoint, the most likely to put the frequency to the best and highest use. And so the economists recommended to the FCC that, in cases of competing applications for frequency band or frequency, that the FCC should go to an auction process where the entities who want that band or that frequency have to bid against each other, and whoever comes up with the highest bid ends up winning that band or that frequency. And so in 1990-

Robert J. Marks:

So if I could interrupt, the criteria changed from how do we best service the public, as opposed to how much money we can make?

Andrew Clegg:

That's a cynical way of looking at it, but not a bad way of doing it. In 1994, that's when the FCC held its first auction, which was basically the first auction in the world for radio spectrum. And one of the earliest bands that was auction for spectrum was the PCS bands, which are basically personal communication services, which is a form of cell phone, is basically essentially 2G, if you're thinking in terms of generations. And they auctioned the 2G spectrum, and they ended up making billions of dollars selling the spectrum. And people suddenly realized, "Look at how valuable radio spectrum is. We can make billions of dollars by auctioning."

Robert J. Marks:

I have a question. Is it literally paying for the frequency band, or is this renting it? Does there have to be a renewal at some point?

Andrew Clegg:

Yes, so it's renting it. The FCC never gives it, never sells. The spectrum is considered to be essentially government or communal property that they don't... It's like a national park or something. So you lease the frequencies, you don't own it. You license the frequencies from the FCC. You're granted a license to use the frequencies if you're the highest bidder.

And then there's what the FCC calls an expectation of renewal. So your license period may run 10 years or 15 years in some cases. And the expectation is that, as long as you've met some basic build-out requirements that you've deployed and you've covered a certain fraction of the population and things like that, that your license will be renewed. Now, the kicker is they don't have to pay again. So those entities who won PCS licenses in 1994 have never had to pay for that spectrum again. It was basically a one-time payment. Their licenses continue to get renewed, but they don't have to pay money for the spectrum again, which is one of the things I think is a bit of an oddity about the auction process.

And so since 1994, the FCC has basically gone to auction whenever there have been competing applications for radio bands or radio frequencies. And when you're talking about radio bands that have been designated for new cell phone systems, for example, the technical rules are such that the bands can be used for cell phone systems. Cell phone systems are very valuable. They generate a lot of money for the Verizon's and AT&T's and T-Mobiles of the country, and so those are natural bands that end up being auctioned. And the amount of money raised at auction keeps going up every year.

And in fact, a couple of years ago, we had an auction for the 3.7 gigahertz band. So there was a lot of spectrum, 280 megahertz of spectrum, which is a lot of bandwidth, and it was almost entirely clear spectrum. The entities that were using that spectrum had to go to different frequencies. And so the cell phone companies didn't have to share those frequencies with anybody. And so that went to auction, and the auction generated a little over $80 billion in winning bid for that spectrum. Plus, the entities had to pay another $14 billion on top of the $80-some billion in order to relocate the incumbents that were in that band to other frequencies. So the winning bidders in that auction paid a collective $90-some billion dollars to access that spectrum.

Robert J. Marks:

Now, let me ask you, Andy, were the bidders cell phone companies? Who were the bidders, and who won?

Andrew Clegg:

The large bidder, large winner, in the auction was Verizon, but AT&T won some spectrum. T-Mobile won some spectrum. Some speculators won spectrum, that is people who were funded to go in and win spectrum, and then hopefully resell it later, or basically sublet it to others, ultimately getting a profit. They also won some, but yes, it was generally the big three cell phone companies that won the spectrum.

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Robert J. Marks:

The big three being Verizon, AT&T, and who?

Andrew Clegg:

And T-Mobile.

Robert J. Marks:

And T-Mobile.

Andrew Clegg:

Yeah. They were the big winners. It's interesting. I'm not an economist, but I think we've gotten to a point with the value of spectrum is so high that no startup could ever afford to compete in an auction for that type of spectrum. And so we will only get the types of networks that Verizon, AT&T, and T-Mobile believe that we should get because they're the only ones that have the kind of money and knowledge to go in and win at these auctions.

The other argument is the money goes to the US Treasury. It doesn't go to the FCC. The money raised at auctions generally goes to the US Treasury. There's some exceptions, some details. If there were government users of the spectrum before the auction that have to be moved somewhere else, some of the auction money can be used to reimburse the government users. But for the most part, the money goes to the US Treasury.

90 some billion dollars sounds like a lot of money, but in terms of the 30 plus trillion dollars of debt the US has, that $90 billion is just kind of a drop in the bucket. Wouldn't it be better if the network operators, instead of giving that money to the government, could actually use it to build out better and better networks?

So there are some people who argue, maybe the auction idea isn't all that great, but at the moment Congress loves it because they love seeing this money come in, and they occasionally use it for pet projects and things like that. Congress is big on this. It's notable the FCC's auction authority expired several months ago, and Congress has yet to reauthorize it. It's just one of the many dysfunctional things about Congress. I think it'll get reauthorized at some point before too long.

But anyway, yes, auction is the way that competing applications are now adjudicated at the FCC.

Robert J. Marks:

But for clarity, this is only for use of this spectrum in the United States, right?

Andrew Clegg:

Correct. When you win an FCC auction, it is only for spectrum that is used in the United States. There are other countries that dabble in auctions as well. But internationally, countries have decided that they will not auction satellite spectrum because the satellite operators basically argue that it would just be too logistically complicated and too expensive to have to go to an auction for the same frequency band in potentially 190 different countries and try to win that band in 190 different countries so you could offer your satellite service worldwide. It would just be too complicated and too expensive. And so countries have generally agreed that they will not auction satellite spectrum.

Robert J. Marks:

Okay. Is there any commonality in the assignment from country to country?

I read, it's kind of an amusing joke about an athlete that went to Mexico, and he bought this great AM radio, and then he returned it. And he says, "Why did you return it?" He says, "Well, I don't need this. It only picks up Spanish stations. I can't understand Spanish."

Is there a commonality of use and requirements from country to country?

Andrew Clegg:

In a way, that's what the International Telecommunication Union is for. They are an agency of the United Nations. 190 some UN member countries participate in the ITU, and they create the radio regulations, which is an international treaty that says, hey, this band will be used for, this band will be used for this, this band will be used for this. And the idea is if every country allocated the same band to the same services, then economy of scale gets better. So if every country allocates the same bands for cell phones, then cell phones can be made with those bands in it, and those same cell phones can be sold all over the world.

So we attempt to do that the best we can, but the reality is the allocations don't end up being totally harmonized around the world, which is okay. The treaty allows countries to choose their own bands the way they want. For example, the original cellular bands were in the 800 megahertz range in the United States, whereas in Europe, they're in the 900 megahertz band. So back in the day when you took your US cell phone over to Europe, it wouldn't work because you don't have the same frequency band. Now, cell phones have a lot more bands built into them. Your typical iPhone or pixel phone or whatever will have both European and American bands built into them, as well as Asian bands and things like that.

But the reality is it would be cheaper to manufacture a cell phone if you could minimize the number of bands you have to support in the phone, because you've got to have antennas that support each band and all sorts of things. So the ideal is to have the bands harmonized around the world, but the reality is they're partially harmonized at best.

Robert J. Marks:

So I'm going to be going to Italy in a few months. Is my cell phone going to work in Italy? Do you know?

Andrew Clegg:

As long, Bob, as you've bought a new cell phone in the last 10 years, 15 years, yeah, it should work fine. It'll have the European bands built into it. Now, if you're talking about your old analog brick phone that you've kept from the 1980s, no, that will not work in Italy.

Robert J. Marks:

Okay. Let me address kind of a sticky subject. I don't know if you guys are going to have any thoughts on this. It turns out, according to Gentleman's Quarterly, the majority of porn is currently watched on mobile devices, and so a lot of the demand that we have for extra spectrum is due to porn. 84% of Pornhub traffic is viewed on mobile devices, and the estimate of the percent time that is used for porn on mobile devices is 13 to 20%.

So a lot of the demand that we have extra spectrum is generated from people that want to watch pornography, and that's disturbing to me. I have no idea what to do about it. Is it just one of these things that goes along with demand, and it has to be addressed?

Andrew Clegg:

Well, I guess a couple of things. Interesting statistic to bring up. I'd have a couple of aspects on that. One is spectrum use reflects the reality of what today's consumers want to do, and if that's what they want to do, then I guess the cell phone companies have to adjust. But the other thing is a lot of that traffic is probably Wi-Fi based instead of cellular network based. We were talking about intensification in an earlier discussion. Everybody has their own Wi-Fi node in their home or apartment or office building or whatever, and so that spectrum gets reused very efficiently. And so to the extent that they're just re-using or five gigahertz or now six gigahertz or whatever, that isn't driving as much of a spectrum crunch.

But yeah, if they're out and about using the macro cellular networks for that kind of data consumption, then yes, that can drive spectrum demand, and you could say that spectrum demand under those circumstances could be driven by pornography. It's an interesting way to look at it.

Robert J. Marks:

Yeah, it really is. But I guess the United States, the First Amendment, is going to allow this. It certainly is allowed the proliferation of porn. Okay, that's a topic for another time.

The other concern that has been made about the selling off of spectrum is that it is spectrum that is used for military purposes. The spectrum is used for military radar. It's used for communications. And there was recent pushback on this from a guy named General Charles C.Q. Brown. He is the Air Force Chief of Staff, but he has been testifying in front of Congress to be the next chairman of the Joint Chiefs of Staff. So this guy is the number one military person, or going to be the number one military person of the United States.

He says that... this is a quote, "That part of the spectrum that is auctioned off is where we have many of our capabilities across the joint force. If we had to vacate that, we'd lose that capability and would have to figure out how to regain that capability and that will take time and cost money."

So what about the claim of General Charles C.Q. Brown, that he's troubled that military bandwidth is being auctioned off for commercial use?

Andrew Clegg:

It's a legitimate concern. I think that quote is most likely specifically about the three gigahertz band.

Robert J. Marks:

Yes. In fact, it's the 3.1 to 3.45 gigahertz band. Yeah.

Andrew Clegg:

Yeah. That band specifically, in most of the world, it's either not used at all by their military or not used much, but that band is used very heavily by our military. In fact, the whole three to basically 3.65 gigahertz band is used by our military for shipborne radars, airborne radars, land-based radars and things, and they've already been required to share the 35.50 to 36.50 megahertz portion with the Citizens Broadband Radio Service. They didn't technically lose that spectrum. They can still operate it more or less like they used to, but because it's shared spectrum, it's always now going to be contested between CBRS and the DOD use. Although again, DOD gets priority in that band.

And then they lost the next lower 100 megahertz, 3.45 to 3.55 when the 3.45 gigahertz service was auctioned off by the FCC. And now they stand to lose the 3.1 to 3.45 gigahertz band because basically the FCC, the DOD and private industry is looking at could the DOD either share that band or be moved out of that band. And so they continue to lose bandwidth around three gigahertz, and they do have a lot of systems that operate in that band.

So I think General Brown is right, but the reality is basically the DOD is facing the same spectrum crunch that everybody else is, and so it's a universal problem.

Robert J. Marks:

Now Austin, I know you have some very interesting perspective on the selling off of US military frequency bands. You could elaborate on that? I think this is very interesting.

Austin Egbert:

Yeah, so my view on it is a little bit different in the sense that if the DOD is concerned about losing access to that spectrum and needing to come up with some other way to make their systems work without having a reserve chunk of spectrum available to them, to me, I'm concerned that the DOD doesn't have the capability to ensure robust access to the spectrum that they need without relying on domestic regulations to reserve that spectrum for them.

Robert J. Marks:

This gets back to the idea that this auctioning off of the spectrum is only valid in the United States. It is not valid in adversarial countries; China, Russia, anywhere else.

Austin Egbert:

Exactly. Or even in Europe or other allied nations. So, like Andy mentioned, this band has been reserved for DOD use in the United States, but not necessarily abroad. I don't know about anyone else; I would prefer that our military systems didn't rely on everyone playing nicely with their systems and making sure that they work, because there's going to be people in the world who don't want the United States Department of Defense systems to work in the way that they're supposed to.

To me, this seems like a red flag of if the DOD saying, yeah, we need everyone to really play nice with our systems to make sure we can do this stuff we need to. You might as well just show up at a country and say, hey, we'd really like you to stop doing something, because otherwise we're going to be sad about it and expecting them to comply. It doesn't seem like a very militaristic way of approaching this type of problem.

You mentioned Staff General Charles Brown. I think part of his quote is that if they had to vacate that spectrum, in the interim they would lose that capability, and they'd have to figure out how to regain it, and they said that would take time and cost money. But at the same time, I think that's exactly what they probably need to do is they need to revisit this problem and actually look at how can we ensure that we're able to use the spectrum regardless of what regulations are in place in a given environment, what reservations are made. How can we show up somewhere and get the job done with whatever is available to us, not having to rely on predetermined spectrum bands and just presuming that everyone else is going to play nicely with that.

He's saying, yeah, it's a problem that we'll lose the capability in the meantime. And I think, yeah, there's probably a short-term issue that shows up there. But I think long-term, if they can make this shift and don't approach it as just, oh, now we're moving to this band, but instead reevaluate how they're considering spectrum usage and move towards just a more adaptive dynamic on-the-fly management of their technologies, then I think it will benefit them significantly in the long run.

So it may just be this is the final push they need to come up with a really robust system that they'll be able to use to their benefit in the long term.

Robert J. Marks:

And I guess to add to your point, I don't think the DOD is being told to vacate that spectrum. Aren't they still sharing that spectrum with the auction spectrum?

Austin Egbert:

Yes. That's how it's working currently in the band that's governed under Citizens Broadband Radio Service, CBRS, as there's a system in place where domestically anyone who's wanting to use that spectrum has to go through a spectrum access system. They would send in a request and say, I'm at XY location. I want to use these frequency bands. And the system will evaluate everyone's requests, do tons of number crunching, and based on its knowledge of where DOD systems are in the world at the moment, will send back an answer of, yes, you can transmit within these power levels, or no, you can't transmit.

The system even has additional protections built in. So, for instance, you can't just rely on DOD systems to know where they're operating, because there's national security concerns, if you don't want everyone to necessarily know what you have positioned where. So there's also a functionality built into this management system that will detect the presence of DOD radars if they come online, and there's a very short timeframe within which it has to kick out any of those spectrum users who aren't DOD systems to make sure that they still have that capability.

Robert J. Marks:

Yeah. I guess the analogy I have is that if the DOD had total control of this within the United States, it's kind of like I'm at one end of the hall, and I'm concerned a fire will start at the other end of the hall, and I want that hallway to be totally cleared of any interference. And they don't like the idea that there's going to be other users in that hall to clutter up the path in case a fire breaks out that they can't get to that fire. On the other hand, if the DOD goes to anyplace else in Europe, Russia, China, whatever, that hall is going to be cluttered because we have no control over what clutter is in that hallway.

I think your point is, Austin, that it would be best if we learned how to operate within that clutter, even organized clutter, better than it would be if that hall were totally clear.

Austin Egbert:

Exactly. Yeah, because otherwise raising this issue is basically just the DOD coming out... It's like in Star Wars. There's the one port on the Death Star that if you fire a missile there, everything comes down. This is the DOD saying, hey, if you show up and bring over a bunch of licensed equipment that's good in Europe, bring that over domestically, set it up near our radars, we'll be powerless to stop you from interfering without physical force or interfering with whatever you're trying to do. But if you were to deploy that, it would have apparently significant issues for their systems.

Robert J. Marks:

I thought your perspective was very, very interesting.

One last question for both of you. It turns out that the demand for spectrum has been increasing exponentially. If you look, there is no case where exponential increase continues forever. It has to level off. It was like the COVID epidemic. They said that there was an exponential rise in COVID cases. When is it going to level off because it can't continue?

When is the demand for spectrum going to level off? Are we getting close, or what do you think?

Andrew Clegg:

I hope it continues to increase so that I have job security.

Robert J. Marks:

Okay. Because as long as it increases, then we have to find ways to mitigate it. Yeah.

Andrew Clegg:

That's exactly right.

Robert J. Marks:

Okay. Austin, you have any thoughts on that?

Austin Egbert:

I agree that it doesn't seem like it's sustainable long term. I have no insight into when it may start to level off. That's the type of prediction that one can make in a vacuum based on present knowledge, and then something revolutionary comes out and all of the former predictions just go out the window. It could be something as simple as somebody comes out with a brand-new widget for an iPhone or Android phone or something, where it's like, yeah, this is the best thing since sliced bread and everyone wants to use it all the time, and now your usage just explodes. Maybe it ends up being where they switch to a different frequency range. Somebody figures out how to fix some propagation issues or signaling, and we start using a Li-Fi or things like that, and offload some spectrum usage somewhere elsewhere where-

Robert J. Marks:

Okay, you used a word people weren't going to know what it is.

Austin Egbert:

Li-Fi is basically Wi-Fi but with frequencies that are closer to the visible range of light. It's more line of sight. You need a direct transmission. I think I've heard rumors that there's been some standards development on that front trying to get closer to being able to deploy something like that. So spectrum usage may go up, but it may be in bands that we aren't currently using, and so that exponential curve may happen, but that doesn't necessarily mean it's going to keep causing problems.

And then there's always the chance you just have some revolutionary technology come out of nowhere. There's been a lot of news recently about LK-99, which is allegedly a room temperature superconductor that has been developed. It's not clear that it is or isn't at this point. There's a lot of conflicting reports. Things have been trending towards, maybe it's not, but it could be the structure's really complex. So there's a lot of uncertainty.

Six months ago, nobody would've been expecting that the world would be talking about the potential of a room temperature superconductor. And if it turns out to be what it is, or ends up working in some capacity or not, it could have a huge impact on what the world of technology and electronics looks like in three or four years time. There's a lot of uncertainty still in play to be able to try and make a forecast like that.

Andrew Clegg:

I think, Bob, another thing. I generally am not a big advocate right now for higher frequencies. When you go to 30 gigahertz and above up to three terahertz, which is the upper range of the regulated radio spectrum, there's a tremendous amount of bandwidth with very good reuse opportunities. Right now, there's a reason why we don't use it. The energy efficiency is very low, propagation is very poor and stuff like that, but we have a lot of smart people, and we'll probably figure out better ways to make use of it. There's more spectrum there than there is in all of the rest of the radio spectrum combined many times over. So maybe that plays a role.

We do come up with new technologies that make significant leaps in spectrum usage. For dispatch radios, we went from single frequencies to trunking systems that greatly increased spectrum efficiency. I saw some statistics lately from Light Reading, I believe, showing that the rate of increase in demand for wireless bandwidth is slowing. So are we getting to the point where we're saturated with a number of videos that we're already watching that we're not needing that much more? And everybody has a phone already.

I don't want to say that we're getting saturated. We don't need more spectrum. But I think there are ways out of our spectrum challenges, and almost certainly it will rely on the development of new and improved technologies for the future.

Austin Egbert:

Yeah, and along those lines, Andy mentioned with everyone having phones, there's only so much video content you can maybe consume at any given time. Even if efficiency improvements are kind of slowing down in the spectrum usage space, I know that video encoding is still a fairly active field, and video compression. Within the last year or so, there's been a new video compression standard that's starting to roll out to devices that greatly reduces the amount of data that you need to transmit a given video signal with the same or better quality as what we're used to now.

There's situations where something like that could potentially end up causing a drop in the demand for spectrum just because you're able to either send the same quality video using much less data, or maybe it'll stay the same, and we'll just scale up the quality of the video that we're sending. But there's other aspects where we can kind of claw back more efficiency in how we're using the spectrum, whether it's on how we manage it at the physical layer in terms of using the frequencies or whether that's a couple layers up the network stack in terms of how we're handling the data we're trying to transmit.

Robert J. Marks:

We don't know what the future is, but we do know that it's going to be mind-blowing and exciting. So that's always a good place to be.

Okay. We're about out of time. Any final thoughts from either Austin or Andy?

Austin Egbert:

I'm good here.

Andrew Clegg:

Yeah, I think I'm good here. It's always hard to predict the future.

Robert J. Marks:

It is.

Andrew Clegg:

But yeah, it'll be fascinating to see what kind of world we're living in, and what 6G ends up being 10 years from now.

Robert J. Marks:

There's an old Danish proverb that says, "Forecasting is dangerous, especially if it's about the future." So that's where we're at right now.

Andrew Clegg:

Totally agree.

Robert J. Marks:

Okay, great.

Hey, we've been talking to a spectrum specialist, Dr. Andrew Clegg from Google, and Dr. Austin Egbert, who is a research scientist at Baylor University. Until next time, be of good cheer.

Announcer:

This has been Mind Matters News with your host, Robert J. Marks. Explore more at mindmatters.ai. That's mindmatters.ai.

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